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The Geological Survey of Greenland
Report No. 86

The Quaternary geology of the Narssaq area, South Greenland

by

Svend Funder

Contribution to the Narssaq Project No. 3
A geochemical-ecological research project

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Abstract

The topography and glacial striations in the Narssaq area indicate that the ice age glacial regime in this part of Greenland was characterized by ice movement constrained by the local topography, and a shallow depth of the ice cover. Erratics observed 1200 m above sea level provide a minimum estimate for the ice thickness.

The most widespread type of glacial deposit consists of scattered boulders lying on the glacially abraded bedrock surface with loose fillings of sand and gravel washed into depressions; this deposit probably reflects the debris content of the ice cover in a final short lasting phase of stagnation and melting. Counting of the boulders and stones shows that the travelling distances generally are short: rock types which are exposed as bedrock less than 1 km away comprise on average 72 % of the material. Some rock types, i.e. the syenites of the Precambrian Ilímaussaq Intrusion, decrease very rapidly in their frequencies as erratics downstream from their exposures, indicating that they were selectively crushed during transportation. The large spatial variation in the 'boulder communities' supports the idea of ice movement being directed by the topography, and poor mixing in the ice sheet.

The low altitudes of the marine limits (47–60 m above sea level) also may be interpreted to reflect shallow ice thicknesses, while the few available dates for the timing of the isostatic upheaval, indicate that the Narssaq area was free of ice *c.* 11 000 years ago.

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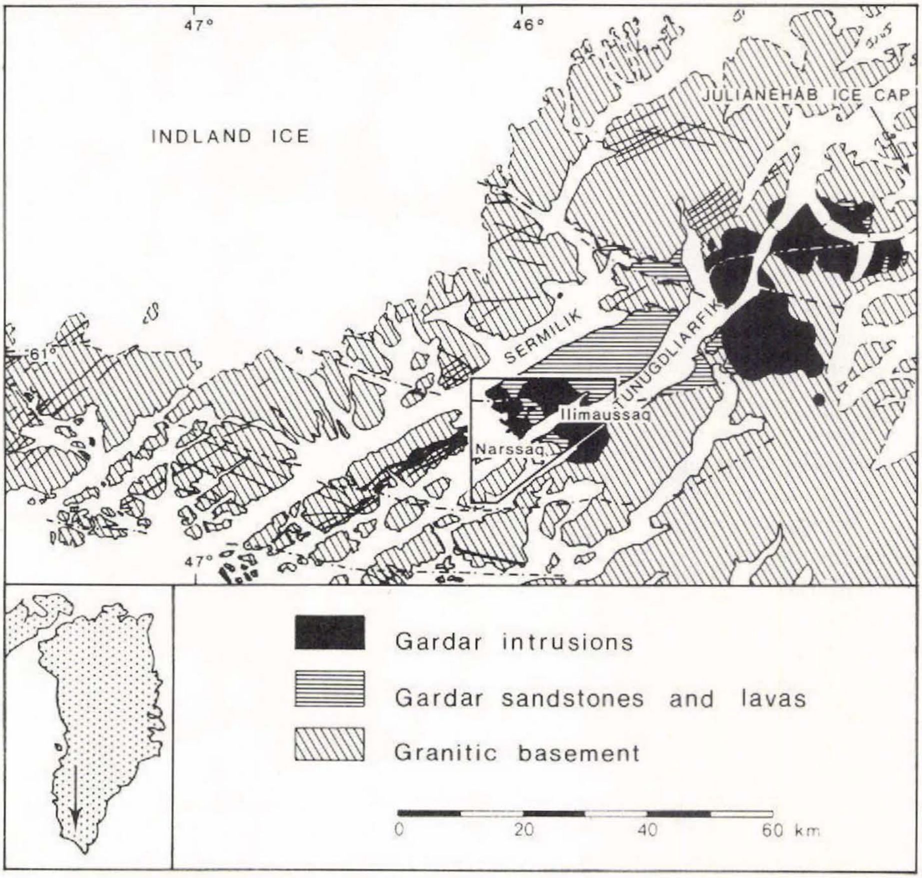


Fig. 1. Main lithological units in the Tunugdliarfik area. (Modified from Watt, 1966).

INTRODUCTION

The present report contains results of field work carried out in the Narssaq area, South Greenland, in 1976. The work was part of the 'Narssaq Project', comprising geochemical and biological investigations in areas within and to the west of the alkaline Ilímaussaq Intrusion (Rose-Hansen *et al.,* 1977).

A main objective of the Quaternary geological work was to provide knowledge on the 'contamination' of the unconsolidated deposits by glacial transport of material from the Ilímaussaq Intrusion, and on the time intervals available for pedological and biological processes in these sediments. These aims were accomplished by establishing the former routes of glacier movement from a study of the forms of glacial erosion, by boulder and stone counts in the glacial deposits, and by investigations on the isostatic history of the area from sampling lakes which have been isolated from the fjords during the isostatic rebound. Unfortunately the latter part of the programme had to be much reduced owing to bad weather.

PREVIOUS INVESTIGATIONS

From the observations made by Steenstrup (1881) and Jessen (1896) it was clear that the whole of South Greenland was once covered by an ice sheet with a general direction of movement towards the outer coasts, and possibly forming terminal moraines on the shelf off the coast. The area has later been subjected to isostatic rebound.

Weidick (1963, 1973) dated the decay of the ice sheet to the end of the last glaciation, the Wisconsin/Weichselian ice age, and stated that the present state of ice coverage probably had been achieved *c.* 9000 years ago in this part of Greenland. He also pointed out that the area is at present squeezed in between the Inland Ice proper to the north and the dynamically independent Julianehåb Ice Cap to the east, and that since during the ice age the ice flowed generally from east to west, it is likely that the Inland Ice proper did not extend significantly beyond its present southern limit.

The present outlet glaciers from the Inland Ice and the Julianehåb Ice Cap have been studied by Lavrushin *et al.* (1970), and Kelly (1974, 1975) has discussed aspects of the isostatic and deglaciation histories of the area.

GEOLOGY AND TOPOGRAPHY

The investigated area measures *c.* 15×15 km and is situated on both sides of Tunugdliarfik, mid-way between the head and mouth of the fjord (fig. 1).

The bedrock geology along the fjord is complex comprising a wide range of rock types: sandstone, quartzite, lavas, granite and the characteristic syenites and nepheline syenites of the Ilímaussaq Intrusion and the intrusions at the head of the fjord (Allaart, 1973). The distribution of the main rock types appears from fig. 1.

The topography in the area is dictated by the local type of bedrock and its resistance to glacial erosion and weathering. The highest altitudes, *c.* 1500 m, are attained by plateau mountains composed of sandstone and lavas of the Precambrian Eriksfjord Formation. Julianehåb Granite, occuring as bedrock in large areas, generally appears with a glacially abraded surface rarely reaching 500 m altitude, while the characteristic and often coarse grained syenites of the Precambrian Ilímaussaq Intrusion form landscapes of irregular topography where the traces of glacial erosion have to a large extent been obliterated by later weathering.

The topography of the area is predominantly characterized by glacial erosion; accumulation of Quaternary sediments has occurred only sporadically.

FEATURES OF EROSION

Large scale glacial erosion forms

The large scale erosion forms include fjords and diffluence valleys and troughs.

Tunugdliarfik fjord is 80 km long, 5-10 km wide and generally 400 m deep. The sides are often steep and 1000 m high above the water line. Tunugdliarfik is part of a system of parallel fjords that trend ENE–WSW along fault controlled lines.

Along the sides of the fjords numerous diffluence valleys and troughs occur (fig. 2). They are characterized by their steep head walls which have a resemblance to cirque walls, but are topped by glacially abraded cols showing that they were formed by ice flowing over from the adjacent fjord basins. The head walls of the valleys may be pierced by narrow canyons (fig. 3); the lack of alluvial deposits at the mouth of the canyons indicate that they were formed by subglacial melt water. In areas near the cols the bedrock surface is often 'hummocky' with small knobs and tarns (fig. 3), indicating irregularities in the flow of the ice.

The frequent occurrence of diffluence troughs and valleys radiating away from the major fjord basins seem to characterize this area, and may be interpreted to reflect shallow ice cover in which the flow was constrained by the local topography and was concentrated along the major fjord basins.

Small scale glacial erosion features

The upland areas between the fjords and valleys, up to altitudes of 1000 m, show traces of glacial abrasion in varying degrees of freshness – apparently determined by differences in resistance to weathering in different types of bedrock. In the fine grained quartzite and lava

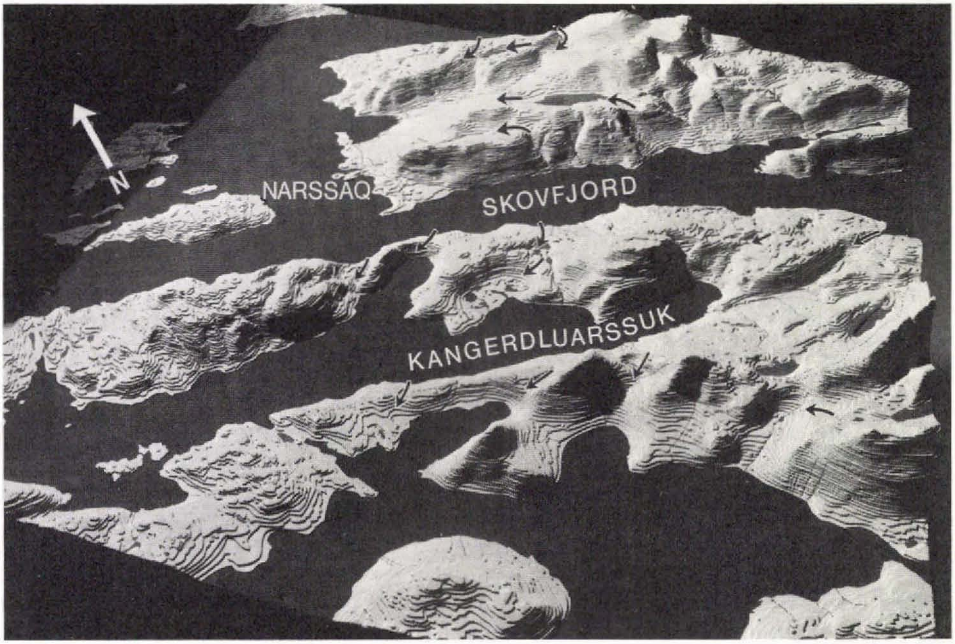


Fig. 2. Diffluence valleys and troughs around Tunugdliarfik. The cols at the head of the valleys are marked by arrows showing the direction of ice flow. The topographic model of the area was made by Mr. Ivan Bohm, Narssaq.

the glacial polish with its fine striation is often preserved, while the coarser granite and syenites show only the coarser grooves and also such features as lunate and crescentic fractures and chattermarks. It should be noted that plastically sculptured forms seem to be rare in all parts.

The mountain plateaux above 1000 m are generally covered by a mantle of sharp edged local boulders (fig. 6).

Fig. 3. Diffluence valley south of Tunugdliarfik looking north towards the col which is pierced by a melt water canyon (centre). The direction of ice movement is towards the observer. In the foreground 'hummocky' bedrock topography.

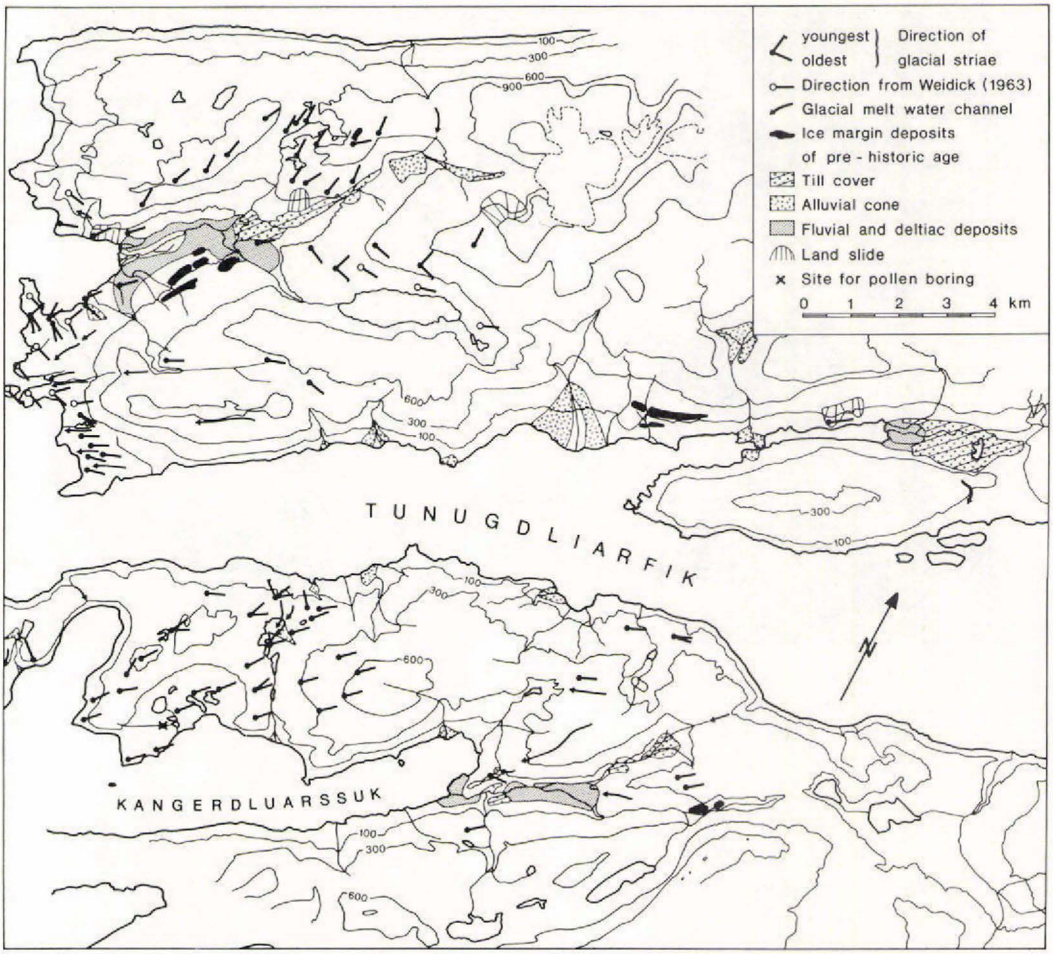


Fig. 4. Quaternary geology of the Narssaq area.

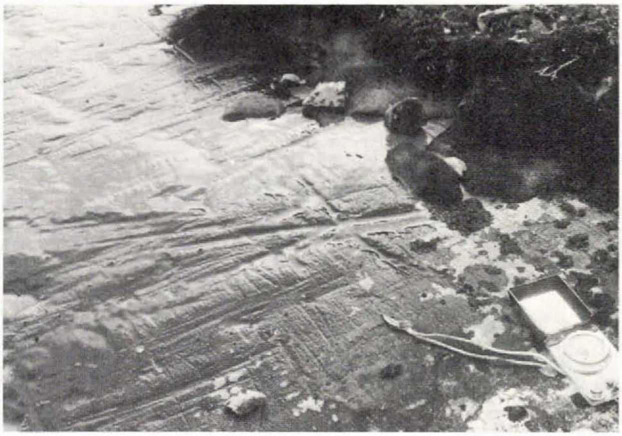


Fig. 5. Crossing sets of striae on a horizontal quartzite surface on the south side of Tunugdliarfik. The coarse grooves running from left to the right are parallel to the direction of the fjord. The age relationship between the different sets at this locality is not clear.

The directions of glacial striations recorded in the area appear from fig. 4. The directions have been measured on horizontal, free lying surfaces.

At all altitudes the directions seem to imply some topographic control of the ice movement, and there is no trace of an old 'cross country' ice movement, such as has been observed in adjacent areas to the north (Graff-Petersen, 1952; Weidick, 1975a). There seems to be a tendency for the striations to diverge at acute angles from the major fjord basins, Tunugdliarfik and Sermilik, supporting the hypothesis mentioned above of shallow ice coverage with movement constrained by topography in all the phases of glaciation that can be recorded.

Striations crossing each other with different directions have been observed in the areas around Narssaq, Narssaq Elvdal and at one locality on the south side of Tunugdliarfik (fig. 5). In the areas around Narssaq and Narssaq Elvdal a relative chronology of ice movement can be deduced from the strations; it comprises three phases (fig. 6):

(1) Ice flowing into Narssaq Elvdal from Sermilik in the north. Striations from this phase of ice movement occur at the north side of the valley. At the head of the valley on the Nákâlâq mountain they have been observed up to 950 m above sea level, the highest striations which have been observed in the

Fig. 6. Narssaq Elvdal looking East from Nákâlâq, with successive phases of ice movement marked.

area. On the south side of the valley they occur around the lake Taseq at 550 m above sea level. This phase of ice movement was followed by (2).

(2) Ice flowing down into Narssaq Elvdal from Tunugdliarfik in the south. Striations from this phase have been observed only on the south side of the valley, near the lake Taseq they cross the older set from the first phase. They have been observed at altitudes up to 700 m. In both these phases ice flowed down Narssaq Elvdal and spread out over the areas around Narssaq and its mouth until they were here followed by another phase of ice movement, (3).

(3) Ice flowed over Narssaq from the south. Whether Narssaq Elvdal at this time was free of ice is not known. Striations from this phase have only been observed at altitudes below 100 m.

At all localities the two sets of striae appear with equal freshness, the older set occurring mainly on the lee side of small stoss and lee forms. The development may be explained as an effect of changes in the glacial drainage pattern caused by the lowering of the ice surface, and the emergence of new topographic barriers.

Glacial melt water channels

Melt water channels, which are now generally dry and run at oblique angles to the topographic gradient, are a common feature in the area. They measure from a few kilometres to a few hundred metres in length, from 30 to 5 m in depth. Their bottom profiles are smooth, and the gradient the same as that of the ice marginal deposits with which they are often associated. They are interpreted to have been formed marginally or submarginally during successive stages of the retreat of the glaciers.

UNCONSOLIDATED SEDIMENTS

Loose Quaternary sediments are generally of sparse occurrence and form a continuous cover only in lowland areas and in the major valleys (fig. 4). From their depositional environment they may be differentiated into marine, fluvial and glacial.

Fig 7. Kame terrace with boulders along the ice contact (right foreground), in the background the kame terrace is transformed into a lateral moraine. The terrace was first observed by Steenstrup (1881) who interpreted it as a raised beach. Taken from 110 m above sea level at Tunuarmiut on the north side of Tunugdliarfik, looking east.

Fig. 8. Lateral moraine (M) and melt water channel (MC) in a small diffluence valley between Tunugdliarfik and Kangerdluarssuk (Reference area III). Direction of ice movement from right to left, looking south to west.

Marine silt and clay occur in the lowland, but are generally hidden by littoral sand and gravel or peat and are known mainly from borings around Narssaq (e.g. Foged, 1975). Fluvial sand and gravel deposited in low gradient deltas occur as river terraces and valley trains in the major valleys and in steep alluvial cones along the fjords, interbedded with beds of unsorted debris. Sorted gravel with many boulders occur in shelves and belts on the mountain sides and have been interpreted as kame terraces (fig. 7).

Till – loose, without structures and poor in silt and clay – forms a continuous cover in restricted areas in some valleys, especially near the valley head, and also composes lateral moraines along the fjords and valleys (fig. 8) and small end moraines deposited by local glacier tongues on Kvanefjeld and the area near Taseq. The moraines are often associated with kame terraces and melt water channels, and they are interpreted as reflecting short lasting stillstands during the retreat of the glaciers.

The most widespread type of glacial deposit in the area is that of scattered boulders which will be dealt with briefly because of its significance to the glacial history.

Scattered boulders

Subangular boulders, 0.2–2 m in diameter, lie on the bare bedrock surface in all parts of the area, often in a perched position (fig. 9). The bedrock surface on which they rest is

Fig. 9. Perched and piled boulders resting on glacially abraded granite. In the background Kangerdluarssuk Fjord.

Fig. 10. Scattered subangular boulders on glacially abraded granite surface with sand and gravel washed into depressions. North of the fjord of Kangerdlu-arssuk looking south.

glacially abraded and its hollows contain shallow fillings of sand and gravel (fig. 10), suggesting the earlier presence of a thin veneer of this material over the bedrock surface.

This peculiar and very widespread type of 'sediment' has been commented upon by Lavrushin *et al.* (1970) who drew attention to the fact that the ice in the present outlet glaciers in the area is very clean and contains very little fine debris; this observation was related to the bedrock lithology which was thought unsuitable as a source for fine grained debris, it was also noted that the area belongs to a general zone of glacial erosion. Graff-Petersen (1952) working in the Frederikshåb area 300 km to the north also drew attention to the very common occurrence of "scattered moraine boulders" which he interpreted as a residue of the ice's basal moraine – the finer fractions having been removed by later mass wasting.

In my opinion the scattered boulders and the accompanying sand and gravel fillings in the bedrock depressions represent the more or less intact debris content in the last body of ice which during a short phase of stagnation was allowed to melt *in situ,* and it is postulated that the abrasion of the underlying bedrock surface dates back to the last phase of active glacier movement, immediately preceding stagnation and melting. These considerations are relevant for the interpretation of the boulder counts below.

BOULDER COUNTS

Stones and boulders have been determined and counted in glacial deposits in all parts of the area (fig. 11), and the results are presented in Table 1.

Each count represents *c.* 100 stones or boulders of uniform size. The localities have been selected to be free of local scree, and they are situated above the marine limit. The types of deposits in which the counts were made comprise the following categories: (a) scattered boulders on bare bedrock surface, (b) stones and pebbles in depressions in the bedrock surface, and (c) stones and boulders from the surface of or exposures in moraines. The large majority of the counts come from sites of type (a). The sites for counting were chosen at random within a suitable area, and all stones or boulders were counted within a circle which was gradually enlarged until a sum of *c.* 100 had been attained. At sites of type (b) and (c)

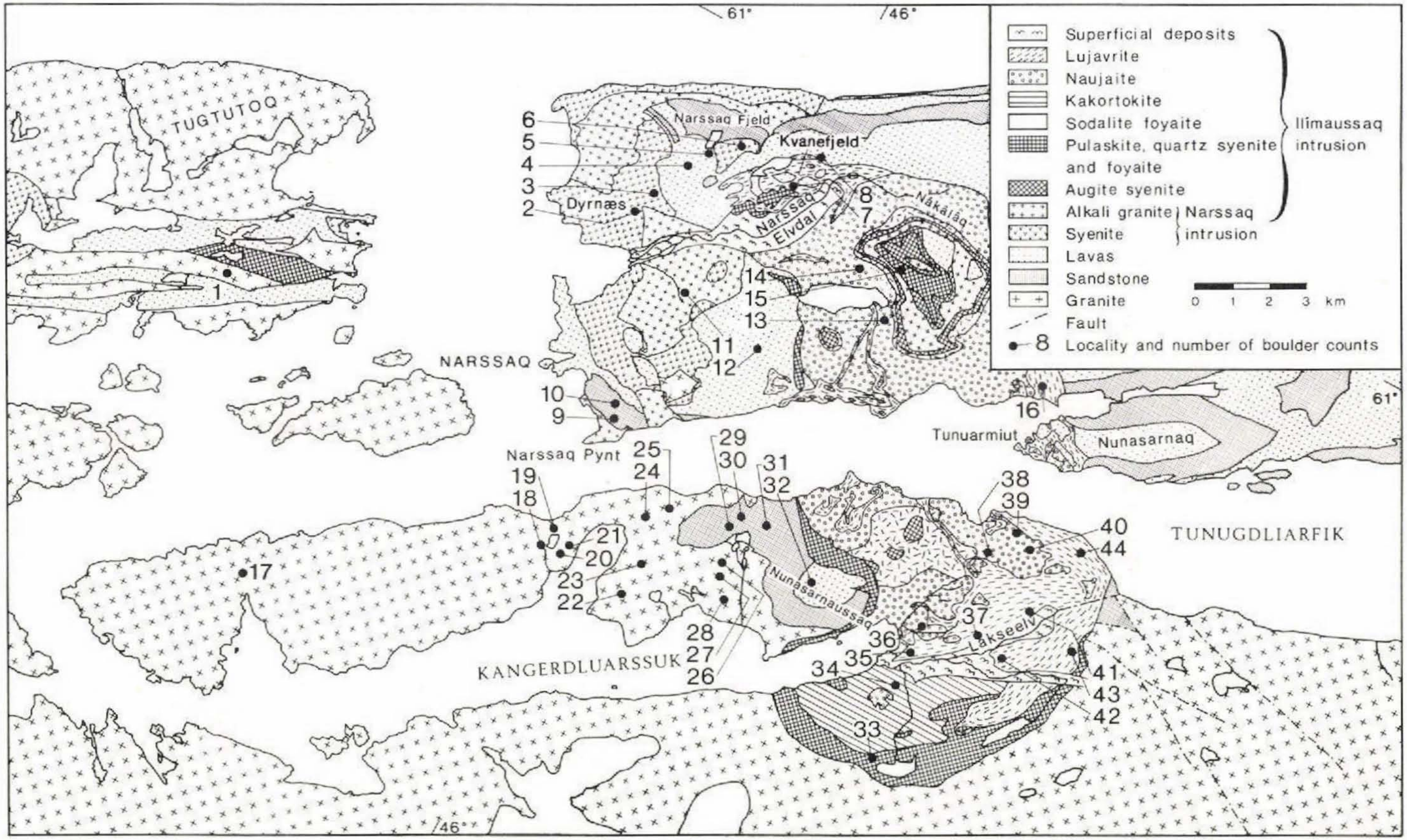


Fig. 11. Geology of the Ilímaussaq area and sites for boulder counts.

Table 1. Stone and boulder counts in the Narssaq area

The frequencies are percentages of the total number of counted stones and boulders.

Locality No	Locality type	Altitude, m above sea level	Fraction counted cm	Number counted	Granite	Sandstone and quartzite	Syenites from the Ilimaussaq Intrusion	Lujavrite	Naujaite	Kakortokite	Augite syenite	Sodalite foyaite	Nepheline syenite	Aplite and pegmatite	Other syenites	Lavas and dolerites
1	a	160	40 - 100	108	23	12	-	-	-	-	-	-	-	1	-	4
2	b	350	3 - 10	116	4	59	2	2	-	-	-	-	-	-	10	25
3	a	605	10 - 20	108	5	61	1	1	-	-	-	-	-	-	-	-
4	a	605	10 - 20	103	5	79	2	2	-	-	-	-	-	-	2	13
5	a	705	40 - 100	104	12	80	-	-	-	-	-	-	-	-	-	9
6	b	800	5 - 10	102	4	77	1	1	-	-	-	-	-	-	3	16
7	b	600	5 - 10	100	8	66	4	4	-	-	-	-	-	-	8	14
8	c	630	20 - 40	100	2	26	4	-	-	-	-	-	-	-	2	66
9	a	65	40 - 150	106	16	34	3	3	-	-	-	-	2	-	4	13
10	a	80	50 - 100	118	9	39	4	4	-	-	-	-	2	-	13	32
11	b	450	20 - 40	106	3	27	17	6	11	-	-	-	-	-	3	51
12	b	800	3 - 10	104	3	22	11	11	-	-	-	-	-	-	7	61
13	c	655	20 - 40	102	2	4	37	25	11	-	-	-	-	-	27	32
14	b	420	5 - 10	105	1	8	53	12	35	-	3	3	-	-	-	22
15	b	1000	10 - 20	104	-	3	60	-	-	-	59	1	-	-	-	26
16	c	110	50 - 150	101	1	34	-	-	-	-	-	-	-	-	-	66
17	a	70	10 - 50	106	48	36	4	2	1	-	1	-	-	-	-	12
18	c	100	10 - 80	103	71	6	8	6	-	-	2	-	-	-	-	16
19	a	120	50 - 200	100	99	-	-	-	-	-	-	-	-	-	-	1
20	a	100	50 - 100	100	92	1	-	-	-	-	-	-	-	-	-	7
21	a	155	50 - 200	103	88	-	-	-	-	-	-	-	-	-	-	12
22	a	150	50 - 150	110	100	-	-	-	-	-	-	-	-	-	-	-
23	a	320	20 - 40	102	12	82	4	4	-	-	-	-	-	-	-	4
24	a	225	40 - 100	105	15	70	16	11	-	-	3	2	-	-	-	-
25	b	105	10 - 30	105	32	-	24	9	4	-	1	10	4	-	-	-
26	a	150	10 - 50	115	35	61	3	3	-	-	-	-	-	-	-	2
27	a	175	20 - 50	102	23	54	18	11	7	-	-	-	-	-	-	3
28	a	165	20 - 150	104	55	37	5	-	2	-	3	-	-	-	-	5
29	a	240	40 - 100	185	2	92	7	2	2	-	3	-	-	-	-	-
30	a	125	20 - 150	104	1	29	68	18	5	-	2	43	-	-	-	-
31	a	205	40 - 100	104	2	59	38	15	8	-	3	12	-	-	-	2
32	a	700	50 - 150	110	-	-	-	-	-	-	-	-	-	-	-	100
33	b	585	5 - 10	110	33	3	67	19	5	19	24	-	-	-	-	1
34	a	200	10 - 40	102	37	30	24	1	-	21	2	-	-	-	-	9
35	b	100	3 - 20	100	23	10	50	46	1	-	3	-	-	-	-	17
36	a	340	50 - 150	102	21	6	68	45	22	-	1	-	-	-	-	5
37	b	460	2 - 10	102	31	32	13	6	7	-	-	-	-	-	-	26
38	b	460	2 - 5	116	-	-	100	4	96	-	-	-	-	-	-	-
39	a	150	20 - 100	101	27	11	58	23	25	-	3	7	-	1	-	4
40	c	270	20 - 40	100	1	-	98	37	53	-	-	8	1	-	-	-
41	b	310	5 - 20	159	23	15	41	14	26	-	1	-	3	-	-	15
42	a	220	30 - 50	102	41	5	54	53	-	-	1	-	-	-	-	1
43	a	330	50 - 150	101	38	35	4	1	2	-	1	-	1	-	-	23
44	a	270	50 - 150	100	82	5	8	8	-	-	-	-	-	-	-	-

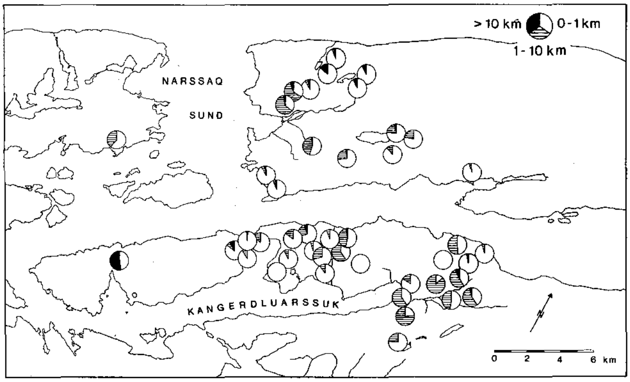


Fig. 12. Percentages of rock types in boulder counts arranged according to distance from nearest known exposure.

this could generally be accomplished within a radius of 1 m, while sites of type (a) often required a radius of 100 m. The size fraction selected for counting at each locality was dictated by the character of the deposits; however, the fraction below 3 cm has not been considered since it did not allow reliable identification of the rock types. Thus, when comparing results from different sites, the difference in the size of the counted fraction should be kept in mind.

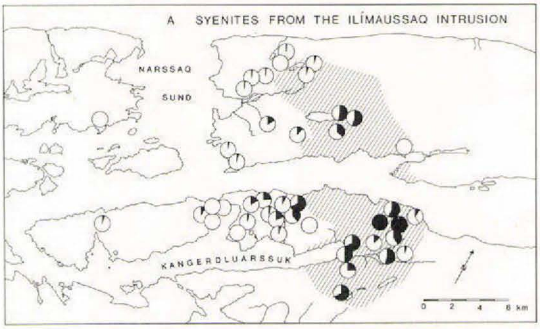
The distribution in the area of some main types of erratics are shown in figs 12 and 13, and in spite of the shortcomings of the observations some general considerations will be ventured.

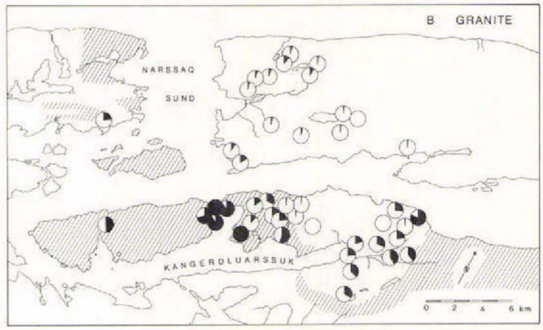
Rock types which can be accounted for by present exposures within a radius of less than 1 km upstream from the counting localities dominate the 'communities' averaging 72 %, whereas rock types with more than 5 km to their nearest present exposure are rare, averaging less than 3 % of the material, but lacking in most samples. Thus the local component seems to dominate the counts, as indicated also by the large spatial variation in the 'communities'. The only rock type identified which does not crop out in the area is nepheline syenite, probably derived from exposures at the head of Tunugdliarfik *c.* 30 km to the east (fig. 1), and though rare in the glacial deposits this rock type can be rather common in raised marine sediments along Tunugdliarfik, showing the importance of transport by floating ice.

The frequency of erratics of Ilímaussaq syenites in areas downstream from their outcrops is variable, but they generally show a rapid decrease: just 5 km west of their exposures as bedrock they are very scanty as erratics (fig. 13a).

Granite (fig. 13b) and sandstones and quartzite (fig. 13c) occur in large areas and probably extend beneath the present ice sheet (Kelly, 1975), and the travelling distances of these rock types is uncertain. However, the good correlation between bedrock geology and the distribution of erratics shows that the far travelled component is at least small. Apparently the decreasing frequency of these rock types away from their exposures is less dramatic than that of the Ilímaussaq syenites, implying that the brittle syenites are selectively crushed, and appear mainly in the fine fractions of the sediments.

The abundance of sandstone and quartzite on Narssaq Fjeld south of Sermilik, and on the northern shores of Kangerdluarssuk in the southern part of the area (fig. 13c) indicates transport from Sermilik and Tunugdliarfik respectively – supporting the interpretation that





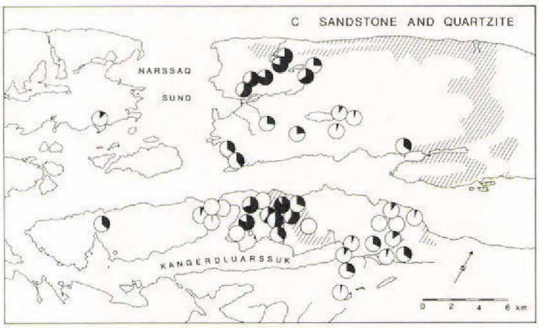


Fig. 13. Percentages of certain rock types in the boulder counts. Their occurrences as exposed bedrock within the area of investigation are shaded in the maps.

the body of ice responsible for the final abrasion of the bedrock surface also transported the boulders.

In general the apparently large local component in the boulder communities and their large spatial variation support the hypothesis of a shallow ice cover with movement constrained by the local topography and consequently poor mixing in the transporting ice.

ISOSTATIC REBOUND

In order to date the retreat of the glaciers it has been attempted to map the marine limit and date the isostatic uplift in the area.

Altitudes of the marine limit are plotted in fig. 14 which includes observations both by earlier authors and myself. The criteria used for identification are listed in Table 2.

There is general agreement between observers, only the values arrived at by Kelly (1974) are slightly higher than those obtained by others; the difference can probably be explained by Kelly's use of the lower limit of perched boulders as his criterion, giving a maximum value for the marine limit, while the raised beaches and deltas used by others represent minimum values.

The marine limit in the area lies between 34 and 60 m above sea level, possibly reaching a maximum in the eastern part of the area. These values are the highest that have been observed along Tunugdliarfik (Weidick, 1973), and are similar to those recorded in adja-

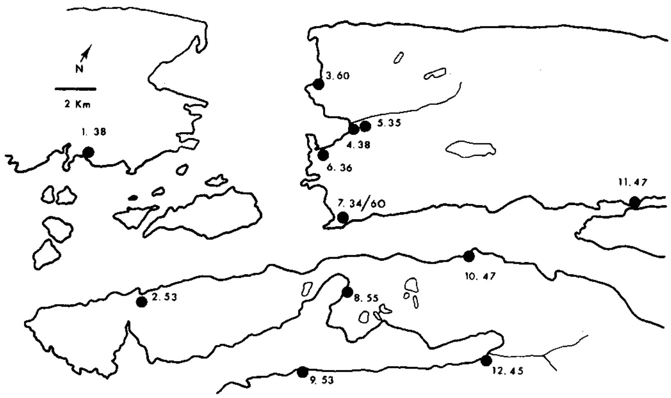


Fig. 14. Marine limits in the Narssaq area, metres above sea level. The locality numbers refer to Table 2.

cent areas to the north (Kelly, 1976), while further north the altitudes of the marine limits increase (Weidick, 1975a; Kelly, 1976).

The dating of the isostatic history has met with difficulties in this area owing to sparsity of datable fossils in the marine sediments. In order to provide some dates it was planned to collect sediments from lakes at different altitudes below the marine limit. However, owing to bad weather, only one lake was sampled, a tarn with its water level 8 m above sea level, on the northern shore of Kangerdluarssuk (fig. 4).

The lake sediment comprises 276 cm of lake gyttja resting with a well defined contact on grey silt with abundant shells of *Mytilus edulis;* the silt was penetrated down to 375 cm below the lake bottom.

The lower three centimetres of lake sediment have been dated to 8260 yr BP (Table 3) which provides a date for the isolation of the tarn from the fjord – and hence a regression from an 8 m sea level.

Compared to other parts of Greenland this date seems very old, and to obtain some control pollen analysis was carried out on some samples of the lake sediment (Table 4). The pollen spectra reflect open vegetation with no shrubs, similar to pollen spectra from the early

Table 2. Observations on the marine limit in the Narssaq area

Locality no	Locality	Nature of the evidence	Altitude, m a.s.l.	Reference
1	Tugtutoq	raised beach, abrasion notch	38	This work
2	Sardlia	perched boulders and trim line	53	Kelly, 1974
3	Narssaq Sund	perched boulders	60	Kelly, 1974
4	Narssap ilua	beach ridge	38	Weidick, 1963
5	Narssaq Elvdal	beach ridge, abrasion notch	35	This work
6	Panernaq	beach ridge	36	Weidick, 1963
7	Narssaq Pynt	beach ridge	34	Weidick, 1963
		perched boulders	60	Kelly, 1974
8	Kangerdluarssuk	perched boulders	55	Kelly, 1974
9	Kangerdluarssuk	perched boulders	53	Kelly, 1974
10	Søndre Siorarssuit	raised beach, delta, abrasion	47	This work
11	North of Nunasarnaq	raised beach, delta, abrasion	47	This work
12	Mouth of Lakseelv	raised beach, delta, cliff	45	This work

Table 3. C-14 dates from the Narssaq area relating to deglaciation and isostatic uplift

Lab. No.	Locality	Material dated	Age, C-14 yr BP	$\delta\,^{13}C$, ‰ PDB	Field altitude m above sea level	Sea level	Reference
I-7664	Narssaq	DW	9410 ± 125	-	12	> 17	Weidick, 1975b
I-7667	Narssarssuaq	S	8760 ± 120	-	10-20	10-20	Weidick, 1975b
K-1744	Comarum Sø, Qagssiarssuk	G	8530 ± 140	-	125	-	Fredskild, 1973
K-2748	Kangerdluarssuk (reference area II)	G	8260 ± 125	-14.8	6	8	This work
Birm 455	Qaleragdlit ima	S	7570 ± 150	-0.27	?	?	Kelly, 1975

DW: driftwood, S: bivalve shells, G: gyttja

phases of vegetation development at Qagssiarssuk in the interior of Tunugdliarfik as well as other sites in south Greenland (Fredskild, 1973; Kelly & Funder, 1974). At the other sites this vegetation phase lasted until 8000–7000 yr BP, when such shrubs as *Alnus crispa, Juniperus communis* and *Salix glauca* immigrated and contributed significantly to the pollen rain. The pollen spectra therefore do not contradict the old age obtained.

In Table 3 C-14 dates with a relevance to former sea levels and ice retreat in the area have been compiled, and in fig. 15 the dates relating to former sea levels are compared to published emergence curves from other parts of West Greenland, indicating that the uplift in the Tunugdliarfik area began some millenia earlier than that in more northerly parts of West Greenland.

Therefore, from the low marine limits it may be inferred that either the ice cover was thinner or the deglaciation slower in this area than in more northerly parts of West Greenland, while the available dates relating to isostatic uplift indicate that the retreat of the glaciers began earlier in this area. By a tentative extrapolation the Narssaq area became ice free around 11 000 yr BP.

CEMENTED SEDIMENTS

A speciality in this area is the frequent occurrence of hard cemented sediments. Although the sediments may be composed of sorted sand and gravel they most commonly consist of poorly sorted mixtures of pebbles, gravel and sand, and have by construction workers and engineers been termed 'tillite'. Since their glacial origin may be questioned it is suggested here that they should be termed diamictite. The localities where I have observed these peculiar sediments are plotted in fig. 16.

The cementation may range from brittle, where the sediment may be broken up with the hands, to hard where a hammer is required. A study of thin sections of these sediments from various localities has revealed that the cement consists of amorphous silica (J. Rose-Hansen, personal communication).

Cemented diamictite has been observed most frequently in alluvial cones interbedded between uncemented, layered sand and gravel (fig. 17), it may also occur in solifluction lobes and has at one locality been observed in fresh scree of naujaite syenite.

Table 4. Pollen types in gyttja from tarn north of Kangerdluarssuk

Sample number	1	2
Betula	1.4 %	0.8 %
Salix herbacea tp	2.3	0.8
Empetrum	3.4	2.2
Loiseleuria tp	0.2	0.2
Oxyria	0.5	0.2
Saxifraga oppositifolia tp	-	0.2
Polygonum viviparus	0.4	-
Thalictrum	0.2	-
Ranunculus	-	0.2
Silene acaulis tp	0.2	0.2
Cerastium-stellaria tp	0.7	0.4
Cruciferae	1.1	-
Dryas	0.2	-
Potentilla	0.2	-
Tubuliflorae	0.2	-
Saxifraga nivalis tp	-	0.2
Plantago maritima tp	-	0.8
Gramineae	33	30
Cyperaceae	9	36
Polypodiaceae	44	26
Cystopteris fragilis	0.7	-
Botrychium	0.2	0.2
Lycopodium alpinum	0.2	0.2
- *annotinum*	0.5	-
- *clavatum*	0.2	-
- *selago*	0.7	0.2
POLLEN SUM	555	503
Pinus	1.6 %	- %
Picea	0.4	0.4
Chenopodiaceae	1.1	1.2
Artemisia	0.4	0.2
Alnus	1.6	0.4
Potamogeton eupot. tp	-	1.4
'Hystrix'	0.4	24.3
Pediastrum, number counted	522	202
Botryococcus, number counted	1	3
LOSS ON IGNITION, % of dry wt.	31	

Sample 1 at 1 cm above contact with marine silt.
Sample 2 at contact with underlying marine silt.

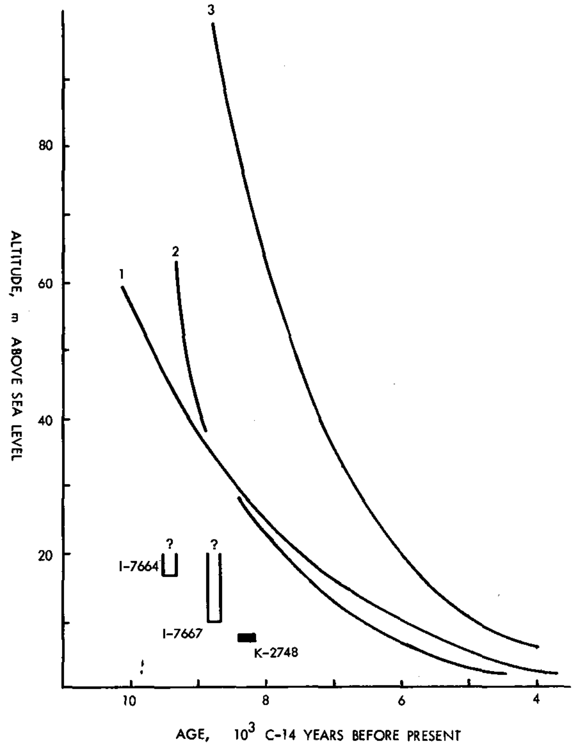


Fig. 15. Emergence curves from West Greenland compared to uplift dates from the Tunugdliarfik area (Table 3). Curve no. 1: Frederikshåb area (Kelly, 1974); no. 2: Nerutussoq – Godthåb (Weidick, 1972); no. 3: Kapisigdlit (Godthåbsfjord) (Weidick, 1972).

The cemented beds often occur near the terrain surface at depths of less than one metre (fig. 18), and when found at greater depths they were always associated with horizons with percolating groundwater.

The field relations of the cemented sediments possibly allow a tentative explanation of their formation.

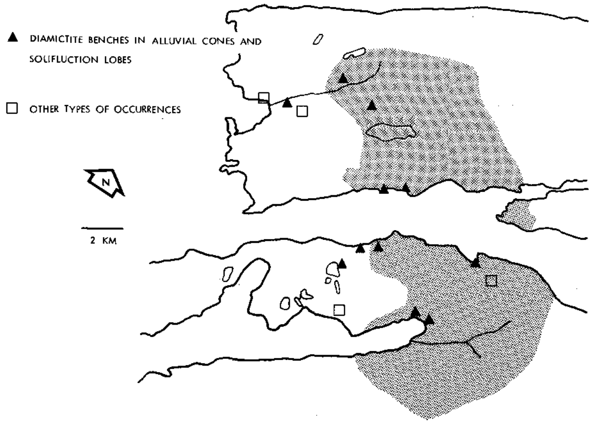


Fig. 16. Localities for cemented sediments. Area of Ilímaussaq Intrusion shaded.

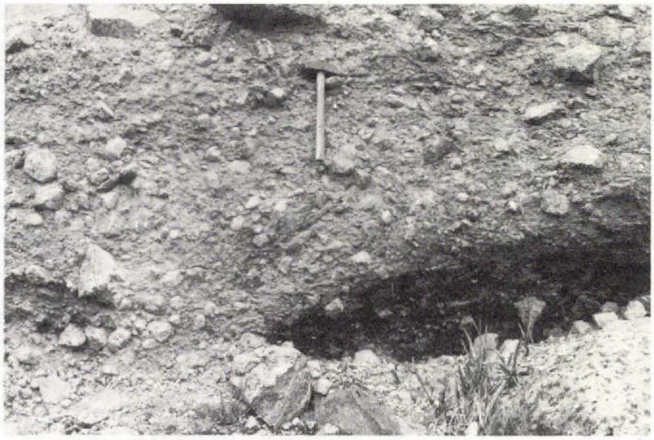


Fig. 17. Cemented diamictite in solifluction lobe exposed in the coastal cliff at the head of Kangerdluarssuk.

(1) The occurrence of the cemented beds near the terrain surface or in association with horizons with percolating groundwater suggests that the cement, amorphous silica, is carried in solution by and precipitated from water seeping down from the surface or groundwater.

(2) The cementation takes place in unsorted sediments selectively because of their high porosity and low permeability.

(3) The cementation process may take place quickly as suggested by the occurrence of cemented benches in unvegetated scree.

(4) The occurrence of cementation coincides with an area of unusual bedrock lithology indicating that the process is related to the particular bedrock geochemistry in this area.

(5) At all localities where cemented diamictite has been observed it could be explained as formed by debris flow or mass wasting, suggesting that when occurring as loose 'boulders' or poorly exposed it is most likely of non-glacial origin.

A possible exception to the last statement is the cemented sediment occurring in the coastal cliffs on the north side of the Narssaq ilua. From this locality Weidick (1963, p. 99) noted the occurrence of boulder clay with impressions of mollusc shells which were considered to be of pre-Holocene age (Weidick, 1963, p. 9).

Fig. 18. Bed of cemented diamictite standing out in section of alluvial cone. Nordre Siorarssuit at north side of Tunugdliarfik.

Unfortunately these sediments are at present only poorly exposed, but at one locality a section has been excavated showing the following sequence of sediments. The figures denote centimetres above sea level.

(1) 600–260: diamicton consisting of silt with a content of sand, pebbles, stones and boulders. The sediment is homogeneous and in the upper part, down to *c.* 350 cm it is penetrated by horizontal and vertical fissures, 1 mm thick and filled with limonite crusts. Cementation occurs from *c.* 350 cm downwards, increasing in intensity so that the sediment between 300 and 250 cm forms a bed which can only be broken by means of a pick axe. Above this hard bed shell impressions occur numerously in a 30 cm thick lens.

(2) 260–240: diamicton dominated by gravel. Loose and unconsolidated and with strong percolation of water. Below this layer the sediment is again fine grained, possibly consisting of laminated silt; however, excavation is hindered by percolating groundwater.

The silty diamicton with shell impressions has been observed along 300 m of the coast cliff; in the western part of the cliff reconnaissance excavations revealed only sand and gravel. The shell impressions occur rather frequently, but concentrated in pockets. The bivalve shells were often paired when 'impressionized', but sometimes fragmented, and not in life position. The impressions comprise both impressions of the outer shell surface with periostracum remnants, and core casts, but no preserved shells have been observed. The composition of the fauna apparently may vary from 'pocket'; in some pockets all impressions come from barnacles, while *Mya truncata* dominate in others. The following species have with some difficulty been identified:

Mya truncata	?*Musculus* sp.
Balanus cf. *sulcatus*	Bryozoan
?*Hiatella arctica*	Snails
?*Portlandia arctica*	Sea urchin

The only item on this list which is not known from the area at present is *Portlandia arctica.*

After the deposition of the sediments a major landslide took place over them and as a possible alternative to Weidick's (1963) interpretation of the sequence it can be suggested that the diamicton could have been formed by mass wasting in Holocene marine and glaci-marine sediments, and disturbance caused by the landslide.

CONCLUSIONS

The directions of glacial striations and the frequent occurrence of landforms formed by diffluence in the glaciers indicate that during the Wisconsin/Weichselian ice age glacier movement was concentrated in and radiated out from the major fjord basins, Tunugdliarfik and Sermilik. Also the low marine limits observed in this area support the concept of ice flow constrained by topography and hence of shallow ice thickness. Erratics observed 1200 m above sea level on the side of Nákâlâq provide a minimum estimate for the thickness of the ice cover.

From the tentative dating of the isostatic uplift it seems likely that the area became free of ice *c.* 11 000 years ago. During the deglaciation process the topography played an increasing role in directing the ice flow as indicated by the complex glaciation history deduced for Narssaq Elvdal. The frequent occurrence of glacially abraded bedrock surfaces with scattered boulders may possibly show that throughout the period of ice margin retreat the glaciers were eroding their substrate, the depositional phase being restricted to a short period following stagnation and melting of small segments of ice. There is no evidence to suggest readvance or significant stillstands of the ice margins in this area during the general period of retreat.

These considerations are in harmony with the picture of glacial transport emerging from boulder counts, and explain the large spatial variation in the boulder 'communities'. The travelling distances for erratic boulders seem to be short; rock types with a known distance of 30 km to their nearest source are very rare, while the majority of types can be explained by the presence of exposures less than one kilometre away from the counting site. A comparison of the frequencies of different rock types in the counts indicate that the Ilímaussaq syenites were selectively crushed during transport and thus may be overrepresented in the fine fractions of the unconsolidated sediments.

The ice age glacial regime outlined here for the Tunugdliarfik area deviates from that inferred from adjacent areas to the north. In the latter areas striations crossing topographic barriers, and higher marine limits (Weidick, 1975a, 1976), as well as the prevalence of landscapes formed by glacial 'areal scouring' (Sugden, 1974) indicate more substantial ice coverage. Two types of factors may be responsible for the apparent variations: differences in the initial topography and regional differences in the development of climates.

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